



Verified Carbon Standard

METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS



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BIOCHAR WORKS

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Relationship to Approved or Pending Methodologies

The following methodology contains the procedures and factors required to determine the greenhouse gas (GHG) benefits of biochar production and utilization. The methodology falls within the Waste Handling and Disposal (WHD) sectoral scope of the Verified Carbon Standard (VCS) Program. Currently available methodologies under VCS Waste Sectoral Scope 13 include VM0018 (energy efficiency associated with solid waste diversion) and VMR0003 (use of organic bedding material). Neither of these methodologies are appropriate for this new methodology. Past biochar methodology efforts under VCS and the American Carbon Registry (ACR) were referenced as part of the development of this new methodology. In addition, the Intergovernmental Panel on Climate Change (IPCC) publication on biochar as well as other programs like the European Biochar Certificate (EBC) are used as reference materials. In total, seven GHG programs and documents were identified that have some relevance to this new biochar methodology, which are listed below in Table 1.

Table 1: Similar Methodologies

Methodology	Title	GHG Program	Comments
v1.0	Methodology for Biochar Projects	American Carbon Registry (ACR)	Carbon Methodology (inactive)
n.d	General Methodology for Quantifying the Greenhouse Gas Emission reduction from the Production and Incorporation into Soil of Biochar in Agricultural and Forest Management Systems	Verified Carbon Standard (VCS)	Carbon Methodology (inactive)
Appendix 4	Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development	Intergovernmental Panel on Climate Change (IPCC)	Biochar guideline for carbon accounting
v2.1	Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil	International Biochar Initiative (IBI)	Certification-Material Standard
v2.1	Guidelines for the Certification of Biochar Based Carbon Sinks	European Biochar Certificate (EBC)	Biochar guidelines for carbon accounting
v2.0	Rules and Methodologies	Puro.earth	Carbon methodology- Trading platform and Certification
v1.3	Carbonfuture Sink Certification Standards	Carbonfuture	Carbon methodology- Trading platform and Certification

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1 SOURCES

This methodology is based on the following sources:

- CDM Small-Scale methodology AMS-III.L: Avoidance of methane production from biomass decay through controlled pyrolysis (Version 2.0).
- CDM Small-Scale methodology AMS-III.E: Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment. Small-scale Methodology (Version 17.0).
- VM0042 Methodology for Improved Agricultural Land Management (Version 1.0).
- CDM EB 23 Report Annex 18. Definition of Renewable biomass.

The following have also informed the development of the methodology:

- Intergovernmental Panel on Climate Change (IPCC). Appendix 4: Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development.

This methodology uses the latest versions of the following CDM tools:

- Tool 03: Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion (Version 03.0).
- Tool 04: Emissions from solid waste disposal sites (Version 08.0).
- Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation (Version 03.0).
- Tool 12: Project and leakage emissions from road transportation of freight (Version 01.1.0).
- Tool 16: Project and Leakage Emissions from Biomass (Version 04.0).

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

This globally applicable methodology provides a framework for the quantification of GHG benefits following the adoption of improved Waste Handling and Disposal (WHD) practices to make biochar. Project activities include the final utilization of biochar in soils or non-soils applications.

The baseline scenario assumes the continuation of pre-project WHD practices of feedstocks that would either be left to decay or be combusted. As this methodology allows for the use of a diverse array of biogenic feedstocks, from forest residues to animal manures to aquatic plants,

the default GHG baseline is considered zero (the most conservative assumption). Hence, the benefits associated with the avoidance of baseline methane generation is not considered in the overall GHG project level accounting in the default baseline scenario. However, at each biochar production facility within the project boundaries, the project proponent can use the default baseline scenario or provide baseline emission factors by applying a 3-year historic look-back period to determine the typical feedstock disposal practices in the project region.

This methodology uses a standardized approach for the demonstration of additionality following an activity method (Table 2) with the processing of waste biomass to biochar as the basis for a positive list. This approach stipulates that the total mass of waste biomass converted to biochar amounts to five percent or less of the total mass of waste biomass available worldwide.

Table 2: Additionality and Crediting Baseline Methods

Additionality and Crediting Method	
Additionality	Activity Method
Crediting Baseline	Project Method

Baseline and project emissions consider the flux of CH₄, N₂O and CO₂ and are defined in units of tonnes of CO₂e. The methodology employs a broad monitoring and accounting framework that captures the GHG impacts into the three important stages of a biochar value chain: sourcing stage, production stage, and application stage (i.e., the use of biochar into soil or non-soil applications). The methodology includes a section to address permanence of biochar including decay rate and reversal risk from natural and non-natural risks (Section 8).

Monitoring shall be conducted for both the baseline and project scenarios. For emissions associated with the production stage, calculations are based on one or more monitored biochar production variables according to the parameters described (e.g., production temperature and biochar material properties) or using default values detailed in the methodology according to the technology type used. Eligible projects must document and prove the final application of biochar (from sales records, invoices, attestations, and other evidence as detailed in Section 9).

Given the diversity within the biochar community, the goal of this methodology is to be as inclusive as possible as it pertains to feedstock sourcing, production technologies, and biochar applications, whilst also ensuring that any GHG benefits are real, additional, and produced according to VCS *Program requirements*.

Therefore, the approach with this methodology is to provide a framework for quantifying emission reduction and removals resulting from the adoption of a biochar technology to dispose of waste biomass. In cases where data exists that can be used for specific biochar applications (such as the IPCC values for soils) that information is listed within the methodology document. In cases where a biochar product use is not listed within this methodology, project proponents are provided with a list of data requirements needed to include these other uses for GHG accounting purposes.

3 DEFINITIONS

In addition to the definitions set out in VCS document *Program Definitions* the following definitions apply to this methodology:

Anaerobic decomposition

Microbial breakdown of organic material in the absence of oxygen. Organic compounds emitted during anaerobic decomposition are mainly methane (CH₄) and lesser amounts of carbon dioxide (CO₂). Examples of anaerobic decomposition include marine mud sediments and manure ponds.

Biochar

A carbon-rich solid material formed by the thermochemical processing of biomass in an oxygen limited environment. These processes can be classified as either pyrolysis (in which oxidants are excluded), or gasification (in which oxidant concentrations are low enough to generate syngas). Biochar is considered a carbon sink when its soil applications (e.g., soil amendment in agricultural lands) or non-soil applications (e.g., cement, asphalt, etc.) can prove carbon stability over time.

Biogenic

Material that is produced or originates from a living organism.

Chain of Custody

Tracking and documenting waste biomass as they are converted to biochar and use in a soil or non-soil application.

Feedstocks

The material undergoing thermochemical processes to create biochar. Feedstock materials must be biogenic to qualify under this methodology and be from the approved list (described in Section 4).

Fixed Carbon Content

Amount of organic carbon stored in the biochar as a mass proportion (in %) based on biochar's dry weight.

Freight

Goods and materials (including waste materials) that are transported. Freight transportation activity under this methodology refers to trips for transporting waste biomass or biochar products. Transportation shall be grouped together as using the same vehicle class and transporting freight between the same origin and destination.

Gasification

A technological process that can convert any carbonaceous raw material into flue gas also known as syngas. Gasification occurs in a gasifier, generally at high temperatures (>700° C).

High-Carbon Fly Ash from biomass

A by-product of biomass-based energy production. High-Carbon Fly Ash (HCFA) from forest biomass is typically produced using boiler systems at lumber and other forestry related facilities. About 1% to 2% of incoming biomass on a dry weight basis becomes HCFA. The main components are ash and carbonized material.

High technology pyrolysis

High technology as defined in this methodology refers to production facilities that meet the following conditions: (a) ability to combust or recover pyrolysis gases, limiting the emissions of methane to the atmosphere; (b) ability to utilize at least 70% of the waste heat during biochar production; (c) pollution controls such as a thermal oxidizer or other emissions controls are present that meet local, national or international emission thresholds; and (d) production temperature is measured and reported.

Low technology pyrolysis

Low technology as defined in this methodology refers to production facilities where (a) pyrolytic gases are mainly combusted in the flame front; (b) emissions are not captured from the pyrolysis process; (c) less than 70% of the produced heat energy is recovered; (d) production temperature is not measured or reported.

Material change

Material changes in feedstocks reflect shifts from one biomass type to a different source of biomass. A 10% or greater shift in total feedstock composition shall constitute a material change in feedstock. A material change in thermochemical production parameters of +/- 50°C occurs if the processing time changes by more than 10%. See Appendix 6 of the IBI Standards (IBI, 2015) for more information.

Non-soil applications

Biochar that is used for other applications besides soil. For example, as an additive in long-lasting products like concrete asphalt, or bio-plastics, animal bedding, feed supplements or as a filtration product. Biochar is not eligible in other non-soil application if the fossil fuel inputs are excessive or result in a loss of more than 50% of the original biochar carbon material (for example, some activated carbons).

Pyrolysis

The thermochemical decomposition of a material or compound into a carbon rich residue, non-condensable combustible gases, and condensable vapors, by heating in the absence or lack of oxygen without any other reagents, except possibly steam (per the CDM).

Waste biomass

Biomass, by-products, residues and waste streams from agriculture, forestry and related industries. Any biomass residue meeting the feedstock requirements included in the methodology are eligible for biochar production and in compliance with any required sustainable feedstock criteria (described in Section 4).

4 APPLICABILITY CONDITIONS

The methodology is only applicable when the final application and utilization of biochar either in soil or non-soil use is permanent, proved, and documented. Further, the project activities must meet the following conditions:

Geographical scope

- The methodology is applicable for project development across the globe.

Technology scope

- The methodology is applicable when biochar is produced from waste biomass through pyrolysis, gasification, and biomass boilers¹ and the biochar is subsequently applied into an end-use (soil or non-soil applications).
- The methodology is applicable to projects using either low or high technology production facilities to produce biochar. High and low technology production facilities as per definition provided in the methodology.
- Biochar producers must have a health and safety program to protect workers from airborne pollutants and other hazards. Biochar production facilities must comply with all air quality and environmental laws and regulations that may apply in the national or subnational jurisdiction in which it is produced.
- Project proponents must present appropriate and adequate evidence including any and all documentation and/or information to demonstrate compliance with all applicable environmental and legal regulations.

Eligible feedstocks and production

- The methodology is applicable when biochar is produced from eligible waste biomass. A non-exhaustive list of waste biomass is provided in Table 3.
- One of the following must be established for the waste biomass to be eligible as feedstock for biochar production:
 - waste biomass utilized as feedstock would have been left to decay.
 - waste biomass utilized as feedstock would have been combusted.
- Eligible feedstock must demonstrate compliance with sustainability criteria when applicable (as described in Table 3).
- Purpose-grown biomass is not included as an eligible feedstock. However, it could be incorporated in future revisions, as modules or tools for this methodology.
- For purposes of project accounting, mixing of feedstocks is not allowed during biochar production and only single feedstocks must be used. Additives such as lime, bentonite, rock powder, clay, or soil can be present as long as they are not more than 10% on a dry matter basis. Further, no chemicals shall be used.

¹ For the purpose of this methodology, the terms pyrolysis, gasification and biomass boilers are used interchangeably.

- Biochar material properties and characteristics must be met according to the technology option selected (high or low technology). For a detailed description, refer to Section 8.
- HCFA from co-generation (co-gen) facilities can be a source of biochar if the final material meets IBI standards². However, no more than 5% of the co-gen facilities waste biomass stream (on an annual basis) can be used for the biochar project activity. Project proponents must also provide information that an 'affirmative' technology was used to extract biochar prior to complete combustion of the waste biomass stream. Project proponents must further demonstrate that the co-gen facility did not use fossil fuel sources to replace the loss of biomass caloric value when they diverted material to the biochar project. Affirmative technologies refer to diversion of "re-injection" HCFA that is dropped out of the combustion stream (for biochar harvesting purposes) instead of allowing complete combustion of the biomass feedstocks during a second pass through the boiler.

Table 3 describes a non-exhaustive list of eligible feedstocks under this methodology.

Table 3: List of eligible feedstocks for biochar production

Feedstock sourcing	Examples (not exhaustive)	Sustainability Criteria
Agricultural waste biomass	- Tree, vine and shrub pruning - Harvest residues such as straw, leaves, stalks, husk, pomace, kernels - Fruits and vegetables residues	If project proponents are using agricultural waste biomass directly from fields and it is not coming from a centralized biomass-processing operation (e.g., food processing facilities), project proponents must provide documentation that the practice is not leading to a decline in soil carbon stocks or a reduction in crop productivity. Feedstock removal is therefore limited to no more than 70% of total residues (Battaglia <i>et al.</i> 2020; Andrew, 2006) .
Forestry and other wood processing	- Off-cuts, sawdust, and other material produced as a by-product of forest management or harvesting operations or any other similar by-product from forest-based industries - Thinnings generated from	Primary raw woody sources coming from forest (as opposed to by-products of mill processing) must prove that biomass comes from sustainable sources and do not lead to deforestation or degradation. Examples of proof of sustainable use includes but is not limited to sustainable management plans

² Section 5.8 of the IBI Biochar Standard v2.1. Available at https://biochar-international.org/wp-content/uploads/2020/06/IBI_Biochar_Standards_V2.1_Final2.pdf

	forest wildfire fuel reduction activities or areas designated by state, provincial, or federal authorities as “overstocked” - Material from pruning or thinning of woody vegetation (not including merchantable timber) such as shade trees, orchards, windbreaks, stream buffers, silvopasture, or invasive removal on rangeland - Diseased trees felled in the course of plantation or woodland management - Bark, chips and hog fuel that have little commercial value (e.g., bark or chips that do not meet size or quality specifications)	approved by a relevant state or regional authority, forestry certification including but limited to Programme for the Endorsement of Forest Certification (PEFC) and Forest Stewardship Council (FSC) or meeting requirements of Renewable Biomass as defined by the CDM tool (EB 23 Report Annex 18)³. When processed timber is used as feedstock, all plastic, rubber, metals, reactive coating (such as paint, glues) must be removed from the feedstock for health and safety reasons (Hedley <i>et al.</i>, 2020; EBC, 2012).
Recycling economy	- Urban green cuttings, non-hazardous municipal green waste - Waste paper	Feedstocks must not contain heavy metals. The biomass is the non-fossil fraction of an industrial or municipal waste (CDM EB 23 Report Annex 18).
Aquaculture plants	- Seaweed, algae waste products	Waste by-products of aquaculture.
Animal manure	- Swine, cattle and poultry farms	Waste by-products of animal husbandry.
High-Carbon Fly Ash	- By-products of cogeneration facilities	No more than 5% of the annual biomass throughput from the co-gen facility is eligible for biochar use.

Eligible biochar end-use application criteria

- Biochar must not be used for energy purposes.
- Biochar is eligible to be utilized and accounted for under the methodology if it is being utilized within one year of its production⁴.

³ Available at https://cdm.unfccc.int/EB/023/eb23_repan18.pdf

⁴ Biochar is subjected to natural decay and permanence of biochar is calculated for a period of 100 years. To adhere to the decay factor established for 100 years, biochar must be utilized in soil or non-soil application, as appropriate, within the first year of its production.

- Biochar is eligible to be used as a soil amendment on land other than wetlands. This includes cropland, grassland, or forest. Biochar can be applied either to the soil surface or subsurface. For surface application, the biochar must be mixed with other substrates such as compost or manure. For subsurface application, the biochar can be either applied as a unique soil amendment or mixed with other substrates.
- When biochar is applied into soils it must comply with biochar material standards to avoid the risk of transferring unwanted heavy metals and organic contaminants to soil. Project proponents must meet the IBI “Standardized Product Definition and Product Testing Guidelines for Biochar That is Used in Soil”⁵ and/or EBC “Guidelines for a sustainable production of biochar”⁶, or national regulations for avoiding soil contaminations.
- Biochar is eligible to be used in non-soil applications including but not limited to cement, asphalt, and plastics. For non-soil applications, project proponents must demonstrate that biochar is a long-lived and stable carbon sink using peer-reviewed literature and/or reliable documentation.
- To establish the decay rate of biochar in a given non-soil application, in the absence of supporting documentation, the project must apply the default decay rate of biochar in soils following a conservative approach.
- Only biochar produced in high technology production facilities, as defined under the methodology, are eligible to be used in non-soil applications.

If the biochar project falls within an existing project boundary of another voluntary or regulated carbon program (e.g., Improved Forest Management, Afforestation/Reforestation) proponents must demonstrate that there is no double counting of GHG benefits.

This methodology is not applicable under the following conditions:

- The methodology cannot be applied if biochar is burned as a fuel (e.g., as a substitute for charcoal or coke) or used in other soil or non-soil applications where biochar cannot be demonstrated as a long-lived and stable carbon sink. Permanence through eligible utilization of biochar must be documented accordingly. Biochar must not be processed into activated carbon, used as a reducing agent in steel industry or other uses that are fossil-fuel intensive. Non-soil applications are ineligible under the methodology if there is a loss of more than 50% of the original biochar produced.
- The methodology is not applicable if the project activity leads to a decrease of other carbon pools, in particular, soil organic carbon degradation on agricultural lands, or excessive removals of forest woody debris or litter. For example, collection of dead wood from a forest (which would not be collected in the absence of the project activity), cannot result in overall property carbon stock declines (per Table 3 criteria above).

⁵ Available at https://www.biochar-international.org/wp-content/uploads/2018/04/IBI_Biochar_Standards_V2.1_Final.pdf

⁶ Available at <https://www.european-biochar.org/biochar/media/doc/ebc-guidelines.pdf>

5 PROJECT BOUNDARY

The spatial extent of the project boundary encompasses the geographic area where:

- initial waste biomass is sourced;
- waste biomass is treated through controlled pyrolysis for the purpose of production of biochar; and
- the final application of biochar in soils or non-soils occur;

as illustrated in Figure 1 below.

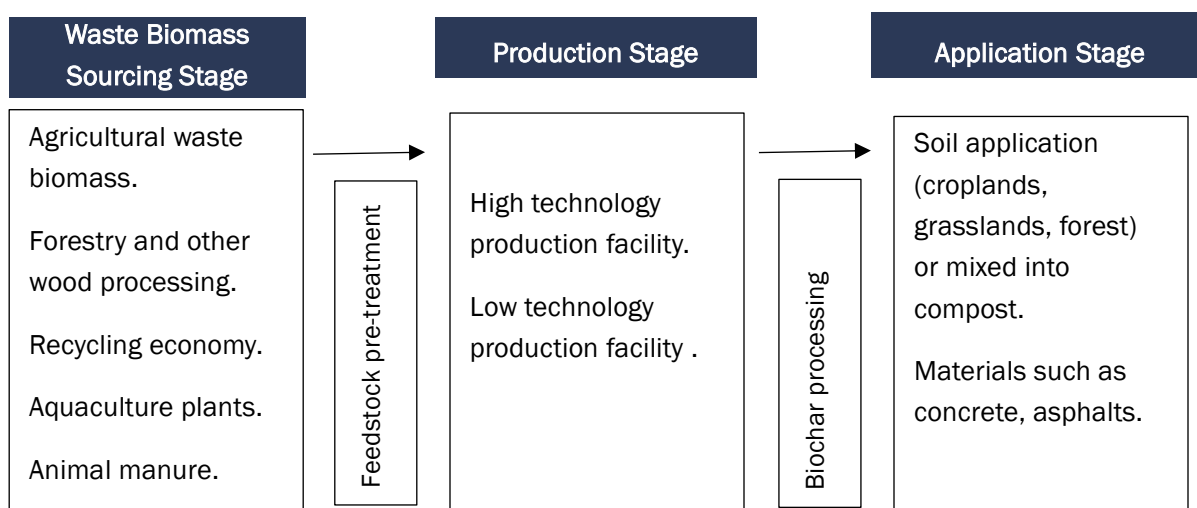


Figure 1: Project boundaries

The greenhouse gases included in or excluded from the project boundary are shown in Table 4.

Table 4: GHG Sources Included In or Excluded From the Project Boundary

Source		Gas	Included?	Justification/Explanation
Baseline	Feedstock production	CO ₂	No	Excluded. Waste biomass are considered renewable per eligibility conditions.
		CH ₄	No	
		N ₂ O	No	
	Feedstock transportation	CO ₂	Yes	Expected to be <i>de minimis</i> if less than 200 kilometers between sourcing sites and production facility.
		CH ₄	Yes	
		N ₂ O	Yes	
	Combustion of feedstocks	CO ₂	Conditional	Default baseline is zero unless project proponent provides data for a baseline emission factor and provides required
		CH ₄	Conditional	
		N ₂ O	Conditional	

Project				documentation (e.g., forest slash emission factors).
	Aerobic decomposition of feedstock	CO ₂	Conditional	Default baseline is zero unless project proponent provides data for a baseline emission factor and provides required documentation (e.g., aerobic decomposition factors for unburned slash).
		CH ₄	Conditional	
		N ₂ O	Conditional	
	Anaerobic decomposition of feedstock	CO ₂	Excluded	Expected to be <i>de minimis</i> .
		CH ₄	Conditional	Default baseline is zero unless project proponent provides data for a baseline emission factor and provides required documentation (e.g., anaerobic decomposition factors for manure lagoon ponds).
		N ₂ O	Conditional	
	Feedstock production	CO ₂	No	Purpose grown crops are ineligible, hence there are no emissions from feedstock production. Waste biomass are also considered renewable per the CDM and project eligibility conditions.
		CH ₄	No	
		N ₂ O	No	
	Pyrolysis, or thermochemical conversion (high technology systems)	CO ₂	No	High technology systems require pollution controls (including methane mitigation) and use of more than 70% of the energy output of pyrolysis.
		CH ₄	No	
		N ₂ O	No	
	Pyrolysis, or thermochemical conversion (low technology systems)	CO ₂	Yes	Low technology systems are provided a default emission value based on published literature (Cornelissen <i>et al.</i> , 2016).
		CH ₄	Yes	
		N ₂ O	Yes	
	Electricity or fossil fuels consumed during pyrolysis	CO ₂	Yes	Included. Emissions associated directly to project activity.
		CH ₄	Yes	Included. Emissions associated directly to project activity.
		N ₂ O	Yes	Included. Emissions associated directly to project activity.
	Biochar transportation	CO ₂	Yes	Expected to be <i>de minimis</i> if less than 200 kilometers between production facility and end-use destination.
		CH ₄	Yes	
		N ₂ O	Yes	

	Pre-treatment of feedstocks (e.g., grinding, drying)	CO ₂	Yes	Included. Emissions associated directly to project activity.
		CH ₄	Yes	Included. Emissions associated directly to project activity.
		N ₂ O	Yes	Included. Emissions associated directly to project activity.
	Biochar application (e.g., preparation of biochar for final use)	CO ₂	Yes	Included. Emissions associated directly to project activity.
		CH ₄	Yes	Included. Emissions associated directly to project activity.
		N ₂ O	Yes	Included. Emissions associated directly to project activity.
	High-carbon fly ash diversion	CO ₂	H*	Expected to be <i>de minimis</i> per 5% diversion requirements.
		CH ₄	H*	Expected to be <i>de minimis</i> per 5% diversion requirements.
		N ₂ O	H*	Expected to be <i>de minimis</i> per 5% diversion requirements.
	Energy production and use	CO ₂	E*	See explanation below.
		CH ₄	E*	See explanation below.
		N ₂ O	E*	See explanation below.

H*—applicability conditions state that qualifying co-gen facilities that divert a portion of their biomass away from renewable energy production to biochar (High-Carbon Fly Ash) must be less than 5% of the total biomass used on an annual basis. In addition, the co-gen facility must demonstrate that they are not replacing the biomass loss with fossil-fuel sources. If both criteria are met, biomass based heat or electrical production loss can be considered *de minimis*.

E*—if the biochar facility sells electricity to the grid under an existing renewable energy program, project electrical generation that displaces fossil fuel-based electricity should not be counted in the calculations (to avoid double counting).

6 BASELINE SCENARIO

Continuation of pre-project waste biomass disposal practices is the most plausible baseline scenario. The baseline scenario is where in the absence of project activity, waste biomass is either left to decay or combusted, and is not utilized for producing biochar for either soil and/or non-soil application. The default baseline emission scenario for the project activity feedstock is zero (a conservative assumption). However, project proponent can provide baseline emission factors for decay rates of manures (and resulting methane emissions) or for combustion of waste biomass in the absence of the biochar-based project activity.

When the project proponent wants to provide baseline emission factors, the project proponent must comply with the following steps:

Step 1: Determination of fate of waste biomass

The yearly emissions in the absence of project activity corresponds to methane emissions from the quantity of the waste biomass diverted for the purpose of biochar production to be used in the project activity. As per the eligibility criteria, the waste biomass can only have two fates: decay or combustion of biomass. The project proponent must determine the proportion of the total waste biomass that would have otherwise either left to decay or combusted in the last 3 years from the start of the project activity.

Step 2: Providing evidence of fate of waste biomass

The project proponent must provide credible evidence of the fate of waste biomass. Examples of evidence include but are not limited to annual government records, records of a waste disposal facility, records of production facility among others. In the absence of records, the project proponent must utilize data from existing literature, existing survey data of similar industries in the same region, or conduct its own survey. The project proponent must then quantify the baseline emissions as per equation 2.

Otherwise, the project proponent must use the conservative approach and consider baseline emissions as zero.

7 ADDITIONALITY

This methodology uses a standardized approach for the demonstration of additionality, specifically an activity method. Activity methods pre-determine additionality for given classes of project activities using a positive list. Projects that implement activities on the positive list are automatically deemed as additional and do not otherwise need to demonstrate additionality. The processing of waste biomass to biochar is the basis for a positive list in this methodology.

Project proponents applying this methodology must determine additionality using the procedure below:

Step 1: Regulatory surplus

The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Standard* and *VCS Methodology Requirements*.

Step 2: Positive List

The applicability conditions of this methodology represent the positive list. The project must demonstrate that it meets all of the applicability conditions, and in so doing, it is deemed as complying with the positive list. The positive list was established using the activity penetration option (Option A in the *VCS Methodology Requirements*).

Activity Penetration

Per the *VCS Methodology Requirements* (section 3.5.9 Option A (c))⁷, Verra will reassess whether the activity penetration levels remain within the permitted threshold within three years of the initial approval of the methodology. At that time, Verra will base its assessment on national boundaries, focusing on countries where biochar made from waste biomass has been used. Also, where sub-national regulations or policies may impact the likelihood of the project activity being implemented, Verra may use such boundaries as the basis of the reassessment of the activity level of penetration .

If the project activity has been commercially available in any area of the applicable geographic scope for less than three years, it shall be demonstrated that the project activity faces barriers to its uptake. Such barriers shall be demonstrated in accordance with Step 3 (barrier analysis) of the latest version of the CDM Tool for the demonstration and assessment of additionality.

Justification for the activity method and step-by-step explanation is provided in Appendix I.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

8.1 Background information

Biochar is made from a diverse array of feedstocks and can be produced with a wide variety of technologies. Life Cycle Assessment (LCA) studies of biochar indicate that the climate benefits of biochar material are highly variable and dependent on many factors. For example, if fossil fuel energy (diesel, gasoline, propane) is used to chip, grind, transport and dry feedstocks then the GHG benefits of biochar to soils and non-soil application can be reduced or eliminated (Sahoo *et al.*, 2021, Hedley *et al.*, 2020; Puettmann *et al.*, 2017)

The same is true for biochar production technologies. In cases where biochar is made with low technology methods (e.g., earth mounds, batch kilns), excess methane can be produced particularly at start-up and shut down, that can counter the long-term sequestration benefits of biochar. Biochar GHG benefits can increase if the syngas or bio-oil produced are used to replace coal-based energy sources. However, the reverse can be true if diesel fuel or propane are used during production or processing feedstocks. Furthermore, the methodology eliminates the use of technologies and feedstocks that lead to health and safety issues, unwanted environmental emissions and contamination risk in soils.

Biochar materials are most commonly used in soil applications; however, non-soil applications are increasingly used for example as animal feed or as an asphalt additive. The total GHG benefits of biochar are therefore influenced not just by the type of feedstocks or the technology used, but also the potential fossil fuel inputs used to create a final product. GHG inputs can

⁷ Available at https://verra.org/wp-content/uploads/2019/09/VCS_Methodology_Requirements_v4.0.pdf

include fossil fuel or electrical energy used for waste biomass pre-treatment or biochar post-treatment.

Given the diversity and complexity of biochar GHG accounting, existing biochar certification programs like the European Biochar Certificate (EBC)⁸ and this methodology limit feedstock types, the technologies that can be used to make biochar, and the type of products that qualify.

8.2 Baseline and Project Emissions

This methodology provides a complete, robust and credible approach to quantifying net GHG emissions reduction and removals resulting from biochar management, including the waste biomass sourcing stage, production stage, and application of biochar stage. Baseline and project emissions consider the flux of CH₄, N₂O and CO₂ and are defined and quantified in terms of tonnes of CO₂e per monitoring period.

To facilitate the future inclusion of further feedstocks and other biochar end-uses, the GHG quantification is set up in a framework, which allows a broad approach to estimate the climate impacts of the biochar value chain. This framework includes:

- the sourcing stage, where waste biomass is sourced and collected,
- the production stage, during which waste biomass is prepared (if applicable) and thermochemically converted into biochar and,
- the application stage, where the biochar is applied into a permanent end-use (in soils or eligible non-soil applications).

8.2.1 Sourcing stage estimations

Emissions at the feedstock sourcing stage are estimated as the sum of the difference between baseline emissions and project emissions in a given year according to the following equation:

$$ER_{ss} = \sum_y (BE_{ss,y} - PE_{ss,y}) \quad (1)$$

Where:

ER _{ss}	Emissions at sourcing stage in year y (tCO ₂ e)
BE _{ss,y}	Baseline emissions at sourcing stage in year y, conservatively assumed as zero as the default value (tCO ₂ e)
PE _{ss,y}	Project emissions at sourcing stage in year y, conservatively assumed as zero (biogenic source material is considered as renewable biomass) (tCO ₂ e). Emissions associated with “in the woods” collection and processing of feedstocks (e.g., diesel use for grinders or chippers) should be counted when applicable in equation 7

⁸ European Biochar Certificate (EBC). Available at <https://www.european-biochar.org/en>

GHG baseline emissions at the sourcing stage

The baseline scenario is the situation where, in the absence of the project activity, waste biomass would have been left to decay or would have been combusted until the end of the crediting period within the project boundary.

Following the CDM Annex 18 on “Definition of renewable biomass”, waste biomass can be classified as renewable. Further, the EBC (2020) also defines a system as carbon neutral “if it is either the residue of a biomass-processing operation, or if the biomass removal did not, over the reference period, lead to the reduction of the total carbon stock of the system in which the biomass had been grown”. Therefore, the feedstock can be considered renewable when the quantity of waste biomass removed does not decrease other carbon pools such as soil organic carbon or dead wood (where applicable). As the decay rate pathway of diverse feedstock types varies by region and time, the methodology defines the default baseline emissions as zero following a conservative scenario.

When the project proponent wishes to include baseline emissions, the following equation shall be used.

$$BE_{ss,y} = BED_{,y} + BEC_{,y} \quad (2)$$

Where:

$BE_{ss,y}$	Sum of the baseline emissions in year y (tCO ₂ e)
$BED_{,y}$	Emissions due to the decomposition of waste biomass in year y (tCO ₂ e). Emissions due to decomposition of waste biomass must be calculated using CDM Methodological Tool 04: Emissions from Solid Waste Disposal Sites ⁹
$BEC_{,y}$	Emissions due to the combustion of waste biomass in year y (tCO ₂ e). Since waste biomass eligible under the methodology is renewable, emissions due to combustion of waste biomass is conservatively considered zero unless project proponent provides acceptable baseline emission factors

GHG project emissions at the sourcing stage

At the sourcing stage as described above, the methodology relies on the collection of waste biomass. Therefore, the emissions directly from cultivating and harvesting biomass for production of biochar ($PE_{ss,y}$) are excluded and the value is set as zero.

⁹ CDM Tool 4: Emissions from Solid Waste Disposal Sites. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-04-v8.0.pdf>

8.2.2 Production stage estimations

In the baseline scenario at production stage, no biochar is produced for the purpose of project activity and therefore no GHG removals or related emissions are considered.

In the project scenario, GHG removals at the biochar production stage refer to GHG emissions from feedstock pre-treatment (when applicable) and from conversion of waste biomass into biochar. The former includes emissions from energy consumption of drying and pre-processing feedstocks, the latter includes other relevant emissions from the production facilities. The project emissions during production at the biochar facility are as follows:

$$ER_{PS,y} = \text{SUM} (CC_{y,t} * \frac{44}{12}) - PE_{PS} \quad (3)$$

Where:

$ER_{PS,y}$	GHG removals at the production stage in year y (tCO ₂ e)
$CC_{y,t}$	Fixed carbon content in year y for biochar based on feedstock and application type t (tCO ₂ e)
PE_{PS}	Project emissions at production stage in the project scenario in year y (tCO ₂ e)
$\frac{44}{12}$	Fraction to convert fixed carbon to tCO ₂ e

As production facilities and technology differ in terms of potential to measure and report relevant parameters, the methodology provides two options (low and high technology) to derive the respective parameters based on characteristics of the technology production facility. Further, as the biochar produced can be utilized differently in the project activity (both in soil and in non-soil applications), different decay rates need to be considered for the respective mass of biochar utilized amongst different applications.

8.2.2.1 Option P.1: High technology production facility

High technology production facilities are defined by the following criteria:

- Ability to combust or recover pyrolysis gases, limiting the emissions of methane to the atmosphere.
- Ability to utilize at least 70% of the waste heat in the production system or within the project boundaries.
- Pollution controls such as a thermal oxidizer or other emissions controls are present that meet local, national or international emission thresholds.
- Production temperature is measured and reported.

Under this methodology, estimated fixed carbon content of the produced biochar is derived from material analysis conducted via established laboratory and standardized methods. Project proponents shall determine fixed carbon content using methods described in the latest version of the IBI “Standardized Product Definition and Product Testing Guidelines for Biochar That is Used in Soil”¹⁰ and/or the EBC “Guidelines for a sustainable production of biochar”¹¹.

If any of the above criteria is not met, the production type is categorized as low technology production facility (see Option P.2).

Step 1: Estimate fixed carbon content (CC) of biochar for high technology facilities

The total fixed carbon content of the produced biochar is the foundation for the GHG calculation. The value is derived from the mass of biochar, its respective carbon content, and the decay rate of fixed carbon in the biochar taken over a period of 100 years (100-year permanence value).

The methodology provides default decay values when the biochar is used in soil application. If the project proponent produces biochar for eligible non-soil applications, the project proponent can either provide a permanence value or by default use the soil decay value.

The total fixed carbon content attributable to the project activity is estimated as follow:

$$CC_{y,t} = M_{y,t} * F_{Cp} * PR_{de} \quad (4)$$

Where:

$CC_{y,t}$	Fixed carbon content in year y for biochar based on feedstock and application type t (tCO ₂ e)
$M_{y,t}$	Mass of biochar of type t applied to the respective end-use in the year y (tonnes) ¹² , see application stage. The produced mass of biochar shall be determined in alignment with CDM tool 13 Option 1 using a weighing device or Option 2 without a weighing device ¹³
F_{Cp}	Organic carbon content of biochar for each production type per tonne of biochar. F_{Cp} for high technology production type defined through material analysis ¹⁴
PR_{de}	Permanence adjustment factor due to decay of biochar (dimensionless) to be defined as per end-use application Soil end-use: For biochar with $H:C_{org} < 0.4$, annual decay of 0.3% as per Budai <i>et al.</i> , 2013; Camps-Arbestain <i>et al.</i> , 2015; and as also adopted by European Biochar Certificate. As permanence is accounted over a period of 100 years, 74%

¹⁰ Available at https://www.biochar-international.org/wp-content/uploads/2018/04/IBI_Biochar_Standards_V2.1_Final.pdf

¹¹ Available at https://www.european-biochar.org/media/doc/2/version_en_9_4.pdf

¹² Tonnes is a metric unit of mass equal to 1,000 kg and equivalent to Megagram (Mg) in the International System of Units. For the purpose of this methodology, the term tonnes has been selected.

¹³ CDM Tool 13. Project and leakage emissions from composting. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-13-v2.pdf>

¹⁴ Material analysis refers to laboratory analysis of biochar.

of the original carbon content is accounted as removal. Value of 0.74 is considered as conservative default for PR_{de}

Non-soil end-use: Where no scientifically robust information on the stability of the carbon content is available, project proponents must use the soil application decay factor mentioned above. Project proponents may propose any other value for PR_{de} as a substitute for the value of 74%. The project proponent must provide evidence of the proposed PR_{de} which must include scientific studies, research papers or any other credible documentation and/or information. Documentation and information such as white papers or non-peer reviewed research papers are not considered as credible and appropriate forms of evidence

Step 2: Estimate project emissions ($PE_{PS,y}$) for high technology production facilities

Emissions under the project scenario are determined using the following equation, which consider the GHG emissions of producing biochar and it shall be calculated as follows:

$$PE_{PS,y} = \text{SUM} \{ (PE_{D,y} + PE_{P,y} + PE_{EC,y}) * (M_{y,t} / M_{x,t}) \} \quad (5)$$

Where:

$PE_{PS,y}$	Project emissions at the production stage in year y (tCO ₂ e)
$PE_{D,y}$	Emissions associated with the pre-treatment of waste biomass in year y (tCO ₂ e)
$PE_{P,y}$	Emissions associated with the conversion of waste biomass into biochar in year y (tCO ₂ e)
$PE_{EC,y}$	Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis (tCO ₂ e)
$M_{y,t}$	Mass of biochar of type t applied to the respective end-use in the year y (tonnes), see application stage
$M_{x,t}$	Total mass of biochar produced in the production facility from feedstock of type t in year y (tonnes)

Emissions associated with the pre-treatment of feedstock in year y ($PE_{D,y}$)

Energy consumption for any necessary pre-treatment of waste biomass shall be accounted for. This can include feedstock preparation (e.g., feedstock agglomeration, homogenization, pelletizing) either inside the production facility or in the field preparation, drying of wet waste biomass, or other processes. If the energy source is renewable, $PE_{D,y}$ is not considered and the default value used shall be zero. $PE_{D,y}$ shall be calculated as follows:

$$PE_{D,y} = \text{SUM}_i (Q_{i,y,energy} * COEF_{i,y}) \quad (6)$$

Where:

$P_{ED,y}$	Emissions associated with pre-treatment of feedstock (tCO ₂ e)
$Q_{i,y, \text{energy}}$	Quantity of energy type i used to pre-treat feedstocks during the year y (mass or volume unit/yr) If the source of energy utilized for pre-treatment of waste biomass is grid connected electricity, $P_{ED,y}$ must be calculated as per CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation¹⁵ Otherwise, it shall be calculated in alignment with the CDM tool¹⁶ to calculate project or leakage CO₂ emissions from fossil fuel combustion
$COEF_{i,y}$	CO₂ emission coefficient of energy type i in year y (tCO₂/mass or volume unit) Coefficient values can be obtained from open-source data such as Greenhouse gas reporting: conversion factors 2020¹⁷ from the Department for Environment, Food & Rural Affairs of the UK government, the United States Environmental Protection Agency factors for gasoline and diesel fuel for transportation¹⁸, or US EPA publication from 2014 on Emission factors for GHG inventories¹⁹

Emissions associated with the thermochemical process (pyrolysis) in year y ($P_{EP,y}$) for high technology facilities

Processing of the waste biomass refers to the pyrolysis process, which fixed the carbon in the biochar. The respective value $P_{EP,y}$ accounts for the emissions from the pyrolysis process, which are emitted into the atmosphere. In alignment with eligibility requirements for high technology production facilities²⁰, net emissions are considered *de minimis*. Therefore,

$$P_{EP,y} = 0$$

Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis ($P_{EC,y}$)

When external energy is required to initiate and maintain the pyrolysis reactor, it shall be accounted for project emissions. If the source of auxiliary energy is renewable, $P_{EC,y}$ is not considered and default value used shall be zero. Otherwise, it shall be calculated as follows:

$$P_{EC,y} = \sum_i (Q_{i,y, \text{energy}} * COEF_{i,y}) \quad (7)$$

Where:

¹⁵ CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation. Available at <https://cdm.unfccc.int/methodologies/PAMethodologies/tools/am-tool-05-v3.0.pdf>

¹⁶ CDM Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. Available at <https://cdm.unfccc.int/methodologies/PAMethodologies/tools/am-tool-03-v3.pdf>

¹⁷ Available at <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020>. Project proponents shall download "conversion factor 2020: full set (for advanced users)" and search "fuels" tab.

¹⁸ Available at <https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s03.pdf>

¹⁹ Available at https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

²⁰ Following requirement (a) of Option P.1: Ability to combust or recover pyrolysis gases, limiting the emissions of methane to the atmosphere.

$P_{EC,y}$	Emissions associated with starting the reactor in the year y (tCO ₂ e)
$Q_{i,y, \text{energy}}$	Quantity of energy type i used to initiate and/or maintain pyrolysis in year y (mass or volume unit/yr) If the source of energy utilized for starting the reactor is grid connected electricity, $P_{EC,y}$ must be calculated as per CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation²¹ Otherwise, it shall be calculated in alignment with the CDM tool²² to calculate project or leakage CO₂ emissions from fossil fuel combustion
$COEF_{i,y}$	CO₂ emission coefficient of energy type i in year y (tCO₂/mass or volume unit) Coefficient values can be obtained from open source data such as Greenhouse gas reporting: conversion factors 2020²³ from the Department for Environment, Food & Rural Affairs of the UK government, the United States Environmental Protection Agency factors for gasoline and diesel fuel for transportation²⁴, or US EPA publication from 2014 on Emission factors for GHG inventories²⁵

8.2.2.2 Option P.2: Low technology production facility

Less advanced technical production facilities that have not been constructed according to industrial standards usually have a lower efficiency to convert organic carbon and often lack emissions controls during the production process. However, these also play an important role in carbon removal associated with production and use in certain cases, e.g., smallholder and farm level settings. Low technology production types are defined by the following criteria:

- Pyrolytic gases are mainly combusted in the flame front.
- Emissions are not captured from the pyrolysis process.
- Less than 70% of the produced heat energy.
- Production temperature is not measured or reported.

Step 1: Estimate fixed carbon content (CC) of biochar for low technology facilities

Just as with high technology settings, in low technology settings the total fixed carbon content of the produced biochar is the foundation of the GHG calculation. The value is derived from the

²¹ CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf>

²² CDM Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf>

²³ Available at <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020>. Project proponents shall download "conversion factor 2020: full set (for advanced users)" and search "fuels" tab.

²⁴ Available at <https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s03.pdf>

²⁵ Available at https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

mass of biochar, its respective carbon content, and the decay rate of fixed carbon in the biochar taken over a period of 100 years (100-year permanence value).

For low technology production facilities, a conservative approach has been selected related to the organic carbon content of biochar (F_{cp}), based on feedstock type and heating temperature as provided in Appendix 1 Table 4 which draws from IPCC (2019) Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development²⁶. In the formula below, permanence (the fraction of biochar carbon remaining after 100 years) is included.

$$CC_{y,t} = M_{y,t} * F_{cp} * PR_{de} \quad (8)$$

Where:

$CC_{y,t}$	Fixed carbon content in year y for biochar based on feedstock and application type t (tCO ₂ e)
$M_{y,t}$	Mass of biochar of type t applied to the respective end-use in the year y (tonnes), see application stage. The produced mass of biochar shall be determined in alignment with CDM tool 13 Option 1 using a weighing device or Option 2 without a weighing device ²⁷
F_{cp}	Organic carbon content of biochar for each production type per tonne of biochar. F_{cp} for low technology production type when possible, determined through material analysis ²⁸ . Otherwise, F_{cp} value are fixed to the Table 5 per type of feedstock for low technology production facility
PR_{de}	Permanence adjustment factor due to decay of biochar (dimensionless) in soils. Biochar is subject to natural decay rate when used in soil applications such as in agriculture, forests, croplands, or grasslands. Many low technology production facilities do not measure the temperature at biochar production, therefore F_{perm} default value of 0.56 ²⁹ shall be used. Value is extracted from IPCC (2019 Figure 4Ap.1) ³⁰ when pyrolysis temperature is unknown. The value follows a conservative approach for carbon permanence

Values for organic carbon content per tonne of biochar per production type (F_{cp})

The determination of the fixed carbon content should be determined in a qualified laboratory. However, project proponents using low technology production facilities can adopt the values from the IPCC (2019) for different feedstocks and production types, which are duplicated here for reference purposes of the F_{cp} value (Table 5).

²⁶ Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch02_Ap4_Biochar.pdf

²⁷ CDM Tool 13. Project and leakage emissions from composting. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-13-v2.pdf>

²⁸ Material analysis refers to laboratory analysis of biochar.

²⁹ Value of 0.56 is taken as the temperature of pyrolysis is not measured, recorded and reported.

³⁰ Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch02_Ap4_Biochar.pdf

Table 5: Values for Organic Carbon content in biochar. Source IPCC (2019).

Values for organic carbon content factor of biochar by production type (F_{cp})		
Feedstock	Production Process	Values for F_{cp}
Animal Manure	Pyrolysis	$0.38 \pm 49\%$
	Gasification	$0.09 \pm 53\%$
Wood	Pyrolysis	$0.77 \pm 42\%$
	Gasification	$0.52 \pm 52\%$
Herbaceous (grasses, forbs, leaves; excluding rice husks and rice straw)	Pyrolysis	$0.65 \pm 45\%$
	Gasification	$0.28 \pm 50\%$
Rice husks and rice straw	Pyrolysis	$0.49 \pm 41\%$
	Gasification	$0.13 \pm 50\%$
Nut shells, pits and stones	Pyrolysis	$0.74 \pm 39\%$
	Gasification	$0.40 \pm 52\%$
Biosolids (paper sludge)	Pyrolysis	$0.35 \pm 40\%$
	Gasification	$0.07 \pm 50\%$

Step 2: Estimate project emissions ($PE_{PS,y}$) for low technology facilities

Emissions under the project scenario are determined using the following equation:

$$PE_{PS,y} = PE_{D,y} + PE_{P,y} + PE_{C,y} \quad (9)$$

Where:

$PE_{PS,y}$ Project emissions at the production stage in year y (tCO_2e)

$PE_{D,y}$ Emissions associated with the pre-treatment of waste biomass in year y (tCO_2e)

$PE_{P,y}$ Emissions associated with the conversion of waste biomass into biochar in year y (tCO_2e)

$PE_{C,y}$ Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis (tCO_2e)

Emissions associated with the pre-treatment of feedstock in year y ($P_{ED,y}$) for low technology facilities

Energy consumption for necessary pre-treatment of waste biomass shall be accounted for. This can include feedstock preparation (e.g., feedstock agglomeration, homogenization, pelletizing,) either inside the production facility or in the field preparation, drying of wet biomass, or other processes. If the energy source is renewable, $P_{ED,y}$ is not considered, and the default value used shall be zero. Otherwise, it shall be calculated as follows:

$$P_{ED,y} = \sum_i (Q_{i,y,energy} * COEF_{i,y}) \quad (10)$$

Where:

$P_{ED,y}$ Emissions associated with pre-treatment of feedstock (tCO₂e)

$Q_{i,y,energy}$ Quantity of energy type i used to pre-treat feedstocks during the year y (mass or volume unit/yr).

If the source of energy utilized for pre-treatment of waste biomass is grid connected electricity, $P_{ED,y}$ must be calculated as per the CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation³¹.

Otherwise, it shall be calculated in alignment with the CDM tool³² to calculate project or leakage CO₂ emissions from fossil fuel combustion

$COEF_{i,y}$ CO₂ emission coefficient of energy type i in year y (tCO₂/mass or volume unit)

Coefficient values can be obtained from open source data such as Greenhouse gas reporting: conversion factors 2020³³ from the Department for Environment, Food & Rural Affairs of the UK government, the United States Environmental Protection Agency factors for gasoline and diesel fuel for transportation³⁴, or US EPA publication from 2014 on Emission factors for GHG inventories³⁵.

Emissions associated with the thermochemical process (pyrolysis) in year y ($P_{EP,y}$) for low technology facilities

In the absence of direct emission measurements which can reliably measure and report project emissions, the following data from the literature shall be used:

³¹ CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation. Available at: <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf>

³² CDM Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf>

³³ Available at <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020>. Project proponents shall download "conversion factor 2020: full set (for advanced users)" and search "fuels" tab.

³⁴ Available at <https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s03.pdf>

³⁵ Available at https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

$$P_{EP,y} = F_e * \sum_{y,t} (M_{y,t} / M_{x,t}) \quad (11)$$

Where:

$P_{EP,y}$	Emissions associated with the conversion of waste biomass into biochar in year y (tCO _{2e})
F_e	Average emissions from producing one tonne of biochar in the year y (tCO _{2e} /tonnes). Adopted values from Cornelissen <i>et al.</i> (2016) ³⁶ can be used where default average emission factor for CH ₄ is 0.09 t CH ₄ /t biochar. The Global Warming Potential (GWP ₁₀₀ for CH ₄ is 28) ³⁷ . Project proponent may propose more appropriate values based on scientific studies, research papers or any other credible documentation and/or information related to the utilized production technology ³⁸
$M_{y,t}$	Mass of biochar from feedstock of type t utilized within the project activity in the end-use application in year y (tonnes)
$M_{x,t}$	Total mass of biochar produced in the production facility from feedstock of type t in year y (tonnes)

Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis ($P_{EC,y}$)

When external energy is required to initiate and maintain the pyrolysis reactor, it shall be accounted for project emissions. If the source of auxiliary energy is renewable, $P_{EC,y}$ is not considered and default value used shall be zero. Otherwise, it shall be calculated as follows:

$$P_{EC,y} = \sum_i (Q_{i,y,energy} * COEF_{i,y}) \quad (12)$$

Where:

$P_{EC,y}$	Emissions associated with starting the reactor in the year y (tCO _{2e})
$Q_{i,y,energy}$	Quantity of energy type i used to initiate and/or maintain pyrolysis in year y (mass or volume unit/yr)
	If the source of energy utilized for starting the reactor is grid connected electricity, $P_{EC,y}$ must be calculated as per CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation ³⁹

³⁶ Available at <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0154617>

³⁷ Value extracted from https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

³⁸ The currently default average emissions per t of produced biochar value exceed the sequestration rate. Without revising F_e with an eligible and lower default emission factor, the project activity will result in higher emissions and thereby become ineligible.

³⁹ CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation. Available at: <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf>

Otherwise, it shall be calculated in alignment with the CDM tool⁴⁰ to calculate project or leakage CO₂ emissions from fossil fuel combustion

COEF_{i,y} CO₂ emission coefficient of energy type *i* in year *y* (tCO₂/mass or volume unit)

Coefficient values can be obtained from open source data such as Greenhouse gas reporting: conversion factors 2020⁴¹ from the Department for Environment, Food & Rural Affairs of the UK government, the United States Environmental Protection Agency factors for gasoline and diesel fuel for transportation⁴², or US EPA publication from 2014 on Emission factors for GHG inventories⁴³

8.2.3 Application stage estimation

Emissions at application stage refer to GHG emissions associated with the post-production and end-use application of biochar. In the baseline scenario at application stage, since no biochar was produced, no carbon removals or related emissions are considered.

In the project scenario, emissions associated with processing and utilizing biochar after its production will have a potential impact on the overall emission removal potential. The equation below determines the GHG emissions at the application stage and it is as following:

$$E_{AS,P} = E_{p,y} + E_{ap,y} \quad (13)$$

Where:

E_{AS,p} Project emissions at application stage in year *y* (tCO₂e)

E_{p,y} Emissions from processing of biochar in the year *y* (tCO₂e)

E_{ap,y} Emissions from application of biochar in the year *y* (tCO₂e)

Emissions associated with processing of biochar (E_{p,y})

In a scenario where biochar undergoes further processing (e.g., sizing, grinding, sifting) before final soil or non-soil application, project proponents must quantify emissions related to grinding and other mechanical transformation of biochar energy related emissions. This methodology does not account for emissions related to the production or generation of materials in which biochar is mixed/infused for non-soil application (e.g., biochar-amended concrete or biochar-amended asphalt).

⁴⁰ CDM Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf>

⁴¹ Available at <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020>. Project proponents shall download "conversion factor 2020: full set (for advanced users)" and search "fuels" tab.

⁴² Available at <https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s03.pdf>

⁴³ Available at https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

If the energy source is renewable, $E_{p,y}$ is not considered and the default value used shall be zero. Otherwise, it shall be calculated as follows:

$$E_{p,y} = \sum_i (Q_{i,y,energy} * COEF_{i,y}) \quad (14)$$

Where:

$E_{p,y}$ Emissions from processing of biochar in the year y (tCO_{2e})

$Q_{i,y,energy}$ Quantity of energy type i used to biochar processing in the year y (mass or volume unit/yr)

If the source of energy utilized for starting the reactor is grid connected electricity, $PE_{C,y}$ must be calculated as per CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation⁴⁴

Otherwise, it shall be calculated in alignment with the CDM tool⁴⁵ to calculate project or leakage CO₂ emissions from fossil fuel combustion

$COEF_{i,y}$ CO₂ emission coefficient of energy type i in year y (tCO₂/mass or volume unit)

Coefficient values can be obtained from open source data such as Greenhouse gas reporting: conversion factors 2020⁴⁶ from the Department for Environment, Food & Rural Affairs of the UK government, the United States Environmental Protection Agency factors for gasoline and diesel fuel for transportation⁴⁷, or US EPA publication from 2014 on Emission factors for GHG inventories⁴⁸

When there is no processing of biochar E_p shall be zero.

Emissions associated with application of biochar (E_{ap})

E_{ap} corresponds to emissions during the application of biochar to the soil. GHG emissions resulting due to fossil fuel combustion and fertilizer application are considered negligible. Thus, E_{ap} is zero⁴⁹.

⁴⁴ CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation. Available at: <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf>

⁴⁵ CDM Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf>

⁴⁶ Available at <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020>. Project proponents shall download "conversion factor 2020: full set (for advanced users)" and search "fuels" tab.

⁴⁷ Available at <https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s03.pdf>

⁴⁸ Available at https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

⁴⁹ As per CDM AR-ACM0003. Available at <https://cdm.unfccc.int/methodologies/DB/C9QS5G3CS8FW04MYXXDF0QDPXWM40E>

8.3 Leakage

Leakage refers to the net increase in anthropogenic GHG emissions outside the project boundary which can be attributed to the project activity. In the case of biochar use, leakage emissions are primarily attributed to the loss of biochar before final application/utilization, in addition to transport emissions at various stages of the biochar life cycle. Emissions due to activity shifting leakage or biomass diversion are considered zero, as currently only waste biomass is eligible for biochar production. Quantification of negative leakage emissions are as follows:

$$LE_y = LE_{bl} + LE_{as} + LE_{bd} + LE_{ts} + LE_{tap} \quad (15)$$

Where:

LE_y	Total leakage GHG emissions due to project activity in the year y (tCO ₂ e)
LE_{bl}	Leakage due to loss of biochar intended for project activity in the year y (tCO ₂ e)
LE_{as}	Leakage due to activity shift (tCO ₂ e). Leakage due to activity shift is zero as purposely grown biomass is not currently allowed for production of biochar
LE_{bd}	Leakage due to biomass diversion (tCO ₂ e). Leakage due to biomass (waste/residue) diversion is considered negligible since only biomass which would have been left to decay or combusted is being utilized for biochar production
LE_{ts}	Leakage emissions due to transport of waste biomass from sourcing to the biochar production facility in the year y (tCO ₂ e). As per CDM Methodological Tool 16: Project and leakage emissions from biomass ⁵⁰ , GHG emissions must only be accounted for if transportation distance is 200 km or more. Project proponent shall use the CDM Methodological Tool 12: Project and leakage emissions from transportation of freight ⁵¹ for calculating LE_{ts}
LE_{tap}	Leakage emissions from transportation of biochar from the production facility to the site of end application in the year y (tCO ₂ e). As per CDM Methodological Tool 16: Project and leakage emissions from biomass ⁵² , GHG emissions must only be accounted for if transportation distance is 200 km or more. Project proponent shall use the CDM Methodological Tool 12: Project and leakage emissions from transportation of freight ⁵³ for calculating LE_{tap}

⁵⁰ CDM Methodological Tool 16: Project and leakage emissions from biomass. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-16-v4.pdf>

⁵¹ CDM Methodological Tool 12: Project and leakage emissions from transport of freight. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf>

⁵² CDM Methodological Tool 16: Project and leakage emissions from biomass. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-16-v4.pdf>

⁵³ CDM Methodological Tool 12: Project and leakage emissions from transport of freight. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf>

Emissions related to leakage due to loss of biochar (LE_{bl})

Loss of biochar refers to scenarios where biochar which was originally intended to be used in the eligible project activity is lost before its application and utilization. These scenarios include but are not limited to loss of biochar due to unexpected combustion of biochar in a warehouse or during transportation, or loss for any other purposes not intended in the proposed and implemented project activity. Calculation for LE_{bl} can be:

- i. Considered zero if the project proponent establishes⁵⁴ that 100% of the biochar originally intended for the application stage is not lost before its application.
- ii. If more than 5% of the biochar is lost (e.g., during transport of the product) then leakage values must be calculated using the following formula:

$$LE_{bl} = \sum_t \left\{ (M_{tl} * F_{Cp} * PR_{de} * \frac{44}{12}) + PE_{PS,y} \right\} \quad (16)$$

Where:

LE_{bl}	Emission related to leakage due to loss of biochar in the year y (tCO ₂ e)
$PE_{PS,y}$	Emissions due to production of the amount of biochar lost in the year y , calculated as per the production facility (tCO ₂ e)
CC_{tl}	Fixed carbon content of biochar lost type t (percentage, dimensionless)
M_{tl}	Mass of lost biochar of type t in the year y (tonnes)
$\frac{44}{12}$	Fraction to convert fixed carbon to tCO ₂ e

Emissions related to leakage from transportation of biochar from production facility to site of end-use application (LE_{tap})

Project emissions from transportation of biochar from facility to end-use application may have the following components:

- i. Transport emissions biochar facility to processing facility; AND
 - ii. Transport emissions processing facility to end-use site;
- OR
- iii. Transport emissions - biochar facility to end-use site.

⁵⁴ Project proponents must provide evidence that no biochar which was intended for the project activity is lost using appropriate evidence, such as invoices, signed attestations, or blockchain records.

LE_{tap} is considered zero if transportation distance is less than 200 km. Calculation of project emissions from transportation of biochar must be done as per the latest version of CDM Tool12: Project and leakage emissions from transportation of freight⁵⁵.

8.4 Risk of reversal

After production of biochar, there are two main sources of reversal risk during the application phase. The first is if the produced biochar is combusted either intentionally (for use as a fuel source) or unintentionally following application to soil via vegetation fires. Per applicability conditions (Section 4.4), the methodology assures that biochar is used only as a soil amendment or in non-soil products, thereby mitigating the risk that biochar will be intentionally combusted.

Unintentional risk of combustion from vegetation fires and other sources of natural risks are described in the following section.

8.4.1 Natural risk

Natural risk includes risks associated with climatic and geological factors such as fire, flood, drought, temperature fluctuation, and precipitation intensity, among others.

8.4.1.1 Natural risks when biochar is utilized for soil application

In project activities where biochar is used as a soil amendment, GHG reversal risk pertaining to natural factors such as fire, drought and floods can be minimized through incorporation of the biochar into soil (to a minimum depth of 10 centimeters). Incorporation of biochar into soil mitigate risks of reversal from fire, drought, or floods.

The nature of changes in soil during fires depends on both the temperatures reached (at different soil depths) and the degree of heating that the different soil components can withstand before being altered (González-Pérez *et al.*, 2004). Studies of fire impacts on soils indicate that temperatures decrease dramatically with soil depth (Enniful, E. K., & Torvi, D. A., 2008) and most soil damage from wildfires are limited to the very top layer of soil (Majder-Łopatka, 2019; Boerner, 2009). With the exception of high-intensity wildfires, the heat generated during a fire does not typically combust the organic matter in soils (particularly in agricultural settings). Thus, when biochar is applied under the top layer of soil, the risk of combustion decreases.

Erosion is another source of natural risk, both water and wind erosion. For water erosion, studies have shown that when biochar is applied into soils, it can mitigate water runoff and

⁵⁵ CDM Methodological Tool 12: Project and leakage emissions from transport of freight. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf>

reduce overall soil erosion (Gholami, L *et al.*, 2019; Lee, S.S *et al.*, 2015). For most water erosion related risk to biochar projects, risk will be minimal.

Regarding wind erosion, risk can be minimized by incorporating biochar into the subsurface of soil; hence, the risks from wind erosion are minimal. Furthermore, with subsoil application, studies have shown biochar increases resilience of the soil to different abiotic and biotic stressors, e.g., application of biochar increases the water retention capacity of the soil (Głąb *et al.*, 2016), thus itself acting as a risk mitigation measure towards natural risk such as fires.

Biochar users can also apply biochar on the soil surface. The International Biochar Initiative recommends mitigating wind erosion risk by mixing biochar with other amendments such as manures and composts. Additionally, formulated biochar products such as mixtures with composts, manures, make biochar less flammable (IBI, 2010). Therefore, the project proponent must mix the biochar with other amendments when applying to the soil surface.

In a scenario when biochar is being used in the soil application and a GHG risk event (e.g., fire, erosion, *etc.*) arises, the following shall apply:

- if the net GHG benefit in the current verification period is positive as compared to that of the previous verification period, a loss event⁵⁶ has not occurred and project shall be only credited for the positive GHG benefits;
- if the net GHG benefit in the current verification period is negative as compared to that of the previous verification period, a loss event has occurred. In such a scenario, the project shall not be issued credit until there is a net positive GHG benefit as compared to the verification period previous to the loss event.

8.4.1.2 Natural risks when biochar is utilized for non-soil application

Natural risk for non-soil applications of biochar are considered minimal. Studies by Lee *et al.*, (2019) have shown that when biochar is used in bio-composites such as those with inorganic clay, biochar reduces thermal conductivity, thus increasing the thermal resistance of the material to combustion. Similarly, biochar infused plastics have shown improved thermo-oxidative stability (Arrigo *et al.*, 2019). When biochar is incorporated into building materials such as mineral plasters, gypsum, or clay, the material is not prone to incineration; rather the biochar is protected against biological and chemical decay (Gupta & Kua, 2019). For this reason, other established biochar accounting programs (i.e., EBC) indicate when biochar is incorporated into building materials such as concrete, lime plaster, gypsum or clay, combustion is nearly impossible (EBC, 2020).

⁵⁶ Loss event as defined in VCS *Program Definitions* 4.1. Available at: https://verra.org/wp-content/uploads/2021/04/Program_Definitions_v4.1.pdf

The above section demonstrates that the natural risks associated with biochar removals are negligible and using the provision of *de minimis*, GHG reversals associated with natural risk for non-soil applications are considered zero.

8.4.2 Non-natural risk

Non-natural risks are those associated with project management, financial viability (for example, insufficient funds to complete the project cycle), government policies, or community and stakeholder resistance, among others. Since the current methodology considers only waste biomass as an eligible feedstock for biochar production, social risks (i.e., community resistance or non-acceptability) substantially decrease and can be neglected.

Project management and financial risks are considered minimal due to the independence of annual removals achieved from project activities. It is possible that the project proponent may go bankrupt at some point after verification and issuance of carbon credits and a project proponent may terminate the project before the end of the crediting period. In that event, non-natural risk due to project and financial viability are considered to have a minimal impact on the previous year project claims because once utilized at the application stage (soil or non-soil application), biochar will remain as a sequestered material. For example, biochar applied to agricultural soils will continue to act as a carbon sink irrespective of the fate of the project and/or continuation of biochar application in the case of project proponent bankruptcy. In the case of a non-soil application project (e.g., biochar infused in cement) the carbon sink function will continue irrespective of subsequent year activities (Akinyemi & Adesina, 2020). GHG benefits associated with biochar applied at project year one are not dependent on continuation of application of biochar in year two.

8.5 Net GHG Emission Reductions and Removals

Net GHG emission reduction and removals are calculated as follows:

$$ER_y = (ER_{PS} + ER_{SS} - ER_{AS}) - LE_y \quad (17)$$

Where:

ER_y	Net GHG emissions reduction and removals in year y (tCO ₂ e)
$ER_{PS,y}$	GHG removals at production stage in year y (tCO ₂ e)
$ER_{SS,y}$	GHG emissions reductions at sourcing stage in year y (tCO ₂ e)
$ER_{AS,y}$	GHG emissions at application stage in year y (tCO ₂ e)
LE_y	Total leakage emissions in year y (tCO ₂ e)

9 MONITORING

9.1 Data and Parameters Available at Validation

Data / Parameter	$M_{y,t}$
Data unit	Tonnes
Description	Mass of biochar of type t applied to the respective end-use in the year y
Equations	Equation 4, Equation 5, Equation 8
Source of data	Data records of biochar production operations using a determined technology for a type of feedstock
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Production of biochar by pyrolysis/gasification process fixes the carbon content from the waste biomass, this way, the carbon is converted into a long-term carbon sink in comparison with the common practices (EBC, 2020). Therefore, the mass of biochar produced must be quantified in relation to the initial waste biomass used and the end-use either in soil or non-soil applications.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	$M_{x,t}$
Data unit	Tonnes
Description	Total mass of biochar produced in the production facility from feedstock of type t in year y
Equations	Equation 5, Equation 11
Source of data	Data records of biochar production operations using a determined technology for a type of feedstock
Value applied	N/A

Justification of choice of data or description of measurement methods and procedures applied	Production of biochar by pyrolysis/gasification process fixes the carbon content from the waste biomass, this way, the carbon is converted into a long-term carbon sink in comparison with the common practices (EBC, 2020). Therefore, the mass of biochar produced must be quantified in relation to the initial waste biomass used and the end-use either in soil or non-soil applications.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	F _{Cp}																
Data unit	Dimensionless																
Description	Organic carbon content of biochar for each production type per tonne of biochar.																
Equations	Equation 4, Equation 8																
Source of data	For high technology production facility: laboratory material analysis following IBI or EBC guidelines on the production of biochar. For low technology production facility, use either a laboratory material analysis or default values from IPCC (2019) Appendix 4 “Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development”																
Value applied	For high technology: N/A For low technology: see table below extracted from IPCC (2019) <table><tr><th colspan="3">Values for organic c content factor of biochar by production type (<i>F_{Cp}</i>)</th></tr><tr><th><u>Feedstock</u></th><th><u>Pyrolysis Production Process</u></th><th><u>Values for F_{Cp}</u></th></tr><tr><td rowspan="2">Animal Manure</td><td>Pyrolysis</td><td>0.38 ± 49%</td></tr><tr><td>Gasification</td><td>0.09 ± 53%</td></tr><tr><td>Wood</td><td>Pyrolysis</td><td>0.77 ± 42%</td></tr></table>			Values for organic c content factor of biochar by production type (<i>F_{Cp}</i>)			<u>Feedstock</u>	<u>Pyrolysis Production Process</u>	<u>Values for F_{Cp}</u>	Animal Manure	Pyrolysis	0.38 ± 49%	Gasification	0.09 ± 53%	Wood	Pyrolysis	0.77 ± 42%
Values for organic c content factor of biochar by production type (<i>F_{Cp}</i>)																	
<u>Feedstock</u>	<u>Pyrolysis Production Process</u>	<u>Values for F_{Cp}</u>															
Animal Manure	Pyrolysis	0.38 ± 49%															
	Gasification	0.09 ± 53%															
Wood	Pyrolysis	0.77 ± 42%															

		Gasification	$0.52 \pm 52\%$
	Herbaceous (grasses, forbs, leaves; excluding rice husks and rice straw)	Pyrolysis	$0.65 \pm 45\%$
		Gasification	$0.28 \pm 50\%$
	Rice husks and rice straw	Pyrolysis	$0.49 \pm 41\%$
		Gasification	$0.13 \pm 50\%$
	Nut shells, pits and stones	Pyrolysis	$0.74 \pm 39\%$
		Gasification	$0.40 \pm 52\%$
	Biosolids (paper sludge)	Pyrolysis	$0.35 \pm 40\%$
		Gasification	$0.07 \pm 50\%$
Justification of choice of data or description of measurement methods and procedures applied	IPCC (2019) states global estimates of organic carbon content of biochar as a function of feedstock and heating temperature and therefore, can be calculated based on a biochar material analysis or using default values (EBC, 2012).		
Purpose of Data	Calculation of project emissions		
Comments	None		

Data / Parameter	PR _{de}
Data unit	Dimensionless
Description	Permanence adjustment factor due to decay of biochar per end-use application
Equations	Equation 4, Equation 8
Source of data	EBC (2020) Guidelines for the certification of biochar based carbon sinks. IPCC (2019) Appendix 4 “Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development” Scientific studies, research papers, other credible documentation

Value applied	For a high technology production facility, project proponents must use 0.74 when biochar is applied into soils and the H:Corg ratio is less than 0.4. For non-soil application, project proponents must demonstrate the decay value of biochar when applied into non-soils uses. For low technology production facility, project proponents must use a conservative default value of 0.56 (IPCC, 2019 – Figure 4Ap.1)
Justification of choice of data or description of measurement methods and procedures applied	Biochar is a stable material that can be used to soil and non-soils applications. As a material, it has a decay rate that must be accounted for. The parameter considers how much of the original carbon will remain in the biochar and can be accounted as a carbon sink after its final application. IPCC and EBC are internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of project emissions
Comments	N/A
Data / Parameter	$Q_{i,y,energy}$
Data unit	Mass or volume unit/year
Description	Quantity of energy type i used for energy related processes
Equations	Equation 6, Equation 7, Equation 10, Equation 12, Equation 14
Source of data	Records and data from project proponent for every process associated with the use of energy in both production and application stage. If the source of energy is grid connected electricity, project proponents must use CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation⁵⁷. Otherwise, it shall be calculated in alignment with the CDM tool to calculate project or leakage CO₂ emissions from fossil fuel combustion⁵⁸.
Value applied	N/A

⁵⁷ CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation. Available at: <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf>

⁵⁸ CDM Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf>

Justification of choice of data or description of measurement methods and procedures applied	External energy is required to operate production facilities. Data must be recorded and provided by the project proponent. Energy consumption is associated with pre-treatment of feedstocks, start and maintain the reactor, and processing of biochar. CDM is internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	$COEF_{i,y}$
Data unit	tCO ₂ / mass or volume unit
Description	CO ₂ emission coefficient of energy type <i>i</i> in year <i>y</i>
Equations	Equation 6, Equation 7, Equation 10, Equation 12, Equation 14
Source of data	Coefficient values can be obtained from open source data such as Greenhouse gas reporting: conversion factors 2020 ⁵⁹ from the Department for Environment, Food & Rural Affairs of the UK government, the United States Environmental Protection Agency factors for gasoline and diesel fuel for transportation ⁶⁰ , or US EPA publication from 2014 on Emission factors for GHG inventories ⁶¹ .
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	External energy is required to operate production facilities. Data must be recorded and provided by the project proponent. Energy consumption is associated with pre-treatment of feedstocks, start of the reactor, and processing of biochar.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	F_e
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⁵⁹ Available at <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020>. Project proponents shall download "conversion factor 2020: full set (for advanced users) and search "fuels" tab.

⁶⁰ Available at <https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s03.pdf>

⁶¹ Available at https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

Data unit	tCO ₂
Description	CO ₂ emissions from producing one tonne of biochar for low technology production facility
Equations	Equation 11
Source of data	Cornelissen <i>et al.</i> (2016) ⁶²
Value applied	Default value for CO ₄ is 0.09 t CH ₄ /t biochar. The Global Warming Potential (GWP ₁₀₀ for CH ₄ is 28) ⁶³
Justification of choice of data or description of measurement methods and procedures applied	Generally, in low technology production facilities, there is no direct measurement of emissions. However, GHG emission must be accounted for and a default gas emission factor for low technology is included.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	M _{ti}
Data unit	Tonnes
Description	Mass of lost biochar of type <i>t</i> in the year <i>y</i>
Equations	Equation 16
Source of data	Data records of biochar lost following a conservative approach.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The methodology addresses the potential leakage due to loss of biochar (i.e., would have been used in soil or non-soil applications but it was lost in the process stage).
Purpose of Data	Calculation of leakage
Comments	N/A

⁶² Available at Cornelissen G, Pandit NR, Taylor P, Pandit BH, Sparrevik M, Schmidt HP (2016) Emissions and Char Quality of Flame-Curtain "Kon Tiki" Kilns for Farmer-Scale Charcoal/Biochar Production. PLoS ONE 11(5): e0154617. doi:10.1371/journal.pone.0154617

⁶³ Value extracted from https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

Data / Parameter	LE _{ts}
Data unit	tCO ₂
Description	CO ₂ emissions from transport of waste biomass from sourcing to the biochar production facility in the year y
Equations	Equation 15
Source of data	Project proponents shall follow the CDM Tool 12 “Project and Leakage emissions from transportation of freight” ⁶⁴ v01.1.0 for calculating the emission associated to the process.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	CDM is internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of leakage
Comments	N/A

Data / Parameter	LE _{tap}
Data unit	tCO ₂
Description	CO ₂ emissions from transportation of biochar from the production facility to the site of end application in the year y
Equations	Equation 15
Source of data	Project proponents shall follow the CDM Tool 12 “Project and Leakage emissions from transportation of freight” ⁶⁵ v01.1.0 for calculating the emissions associated with the process.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	CDM is internationally recognized and the data provided in the guidelines is peer reviewed.

⁶⁴ Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf>

⁶⁵ Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf>

Purpose of Data	Calculation of leakage
Comments	N/A

9.2 Data and Parameters Monitored

Data / Parameter:	$M_{y,t}$
Data unit:	Tonne
Description:	Mass of biochar of type t applied to the respective end-use in the year y
Equations	Equation 4, Equation 5, Equation 8, Equation 11
Source of data:	Data records of biochar produced
Description of measurement methods and procedures to be applied:	Project proponents using both technology facilities shall follow CDM tool 13 Option 1 using a weighing device or Option 2 without a weighing device ⁶⁶ .
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	See Section 9.3
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	F_{Cp}
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⁶⁶ CDM Tool 13. Project and leakage emissions from composting. Available at <https://cdm.unfccc.int/methodologies/PAMethodologies/tools/am-tool-13-v2.pdf>

Data unit:	Dimensionless
Description:	Organic carbon content of biochar for each production type per tonne of biochar.
Equations	Equation 4, Equation 8
Source of data:	For high technology production facility: laboratory material analysis following IBI or EBC guidelines on the production of biochar. For low technology production facility, use either a laboratory material analysis or default values from IPCC (2019) Appendix 4 “Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development”
Description of measurement methods and procedures to be applied:	For high technology production facility: laboratory material analysis following IBI or EBC guidelines on the production of biochar. For low technology production facility, use either a laboratory material analysis or default values from IPCC (2019) Appendix 4 “Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development”
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	See Section 9.3
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	PR_{de}
Data unit:	Dimensionless
Description:	Permanence adjustment factor due to decay of biochar per end-use application

Equations	Equation 4, Equation 8
Source of data:	EBC (2020) Guidelines for the certification of biochar based carbon sinks. IPCC (2019) Appendix 4 “Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development”. Scientific studies, research papers, other credible documentation
Description of measurement methods and procedures to be applied:	For a high technology production facility, project proponents must use 0.74 when biochar is applied into soils and the H:Corg ratio is less than 0.4. For non-soil application, project proponents must demonstrate the decay value of biochar when applied into non-soils uses. For low technology production facility, project proponents must use a conservative default value of 0.56 (IPCC, 2019 – Figure 4Ap.1)
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	See Section 9.3
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$Q_{i,y,energy}$
Data unit:	Mass or volume unit/year
Description:	Quantity of energy type i used for energy related processes
Equations	Equation 6, Equation 7, Equation 10, Equation 12, Equation 14
Source of data:	Records and data from project proponent for every process associated with the use of energy in both production and application stage.
Description of measurement methods	External energy is required to operate production facilities. Data must be recorded and provided by the project proponent. Energy

and procedures to be applied:	consumption is associated with pre-treatment of feedstocks, start and maintain the reactor, and processing of biochar. If the source of energy is grid connected electricity, project proponents must use CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation ⁶⁷ . Otherwise, it shall be calculated in alignment with the CDM tool to calculate project or leakage CO ₂ emissions from fossil fuel combustion ⁶⁸ .
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	See Section 9.3
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	M_{tl}
Data unit:	Tonne
Description:	Mass of lost biochar of type t in the year y
Equations	Equation 16
Source of data:	Records and data from project proponent for biochar lost following a conservative approach.
Description of measurement methods and procedures to be applied:	N/A
Frequency of monitoring/recording:	Annual

⁶⁷ CDM Methodological Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf>

⁶⁸ CDM Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf>

QA/QC procedures to be applied:	See Section 9.3
Purpose of data:	Calculation of leakage
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	LE _{ts}
Data unit:	tCO ₂
Description:	CO ₂ emissions from transport of waste biomass from sourcing to the biochar production facility in the year y
Equations	Equation 15
Source of data:	Records and data from project proponent documenting transportation.
Description of measurement methods and procedures to be applied:	Project proponents shall follow the CDM Tool 12 “Project and Leakage emissions from transportation of freight” ⁶⁹ v01.1.0 for calculating the emission associated to the process.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	See Section 9.3
Purpose of data:	Calculation of leakage
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	LE _{tap}
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⁶⁹ Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf>

Data unit:	tCO ₂
Description:	CO ₂ emissions from transportation of biochar from the production facility to the site of end application in the year y
Equations	Equation 15
Source of data:	Records and data from project proponent documenting transportation.
Description of measurement methods and procedures to be applied:	Project proponents shall follow the CDM Tool 12 “Project and Leakage emissions from transportation of freight” ⁷⁰ v01.1.0 for calculating the emissions associated with the process.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	See Section 9.3
Purpose of data:	Calculation of leakage
Calculation method:	N/A
Comments:	N/A

9.3 Description of the Monitoring Plan

Monitored parameters are collected and recorded at project boundaries, and emission reduction and removals are estimated independently. The project proponent must develop and apply a monitoring plan that allows the quantification and proof of GHG emissions at the three stages covered by this methodology: sourcing, production, and application. The monitoring plan must detail the procedures for data capture, measurement and reporting of the data parameters listed in Section 9.2. Project proponents must include sufficient data capture such that the mass and energy balance may be easily performed and tracked. The main objective of the monitoring is to prove the carbon sink from the final application of biochar and to quantify the emissions resulting from the project scenario during the project crediting period, prior to each verification. Therefore, the project proponent must be able to demonstrate the biochar application for which it is claiming emission removals. In order to do so, project proponents

⁷⁰ Available at <https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf>

must provide detailed biochar application records for the amount of biochar incorporated into a soil or non-soils end-use.

The project proponent shall establish and apply quality management procedures to manage data and information. Written procedures should be established for each measurement stage outlining responsibility and timing requirements (e.g., mass of biochar produced and production date).

Where measurement and monitoring equipment is used (e.g., to measure temperature), the project proponent must ensure the equipment is calibrated according to current good practice (e.g., relevant industry standards, manufacturer specifications or device supplier). Where a project proponent carries out a material laboratory analysis, they must ensure it follows international standards or norms.

Project proponents must detail the procedures for collecting and reporting all data and parameters listed in Section 9. Box 1 shows the different types of information sources for record and monitor the project activity based on a high to low preference.

Box 1.

A robust control system is in place capable of ensuring that all the applicable requirements are implemented by the project proponent. Quantitative sources of information and record keeping practices on biochar sourcing, production and application stages must be chosen with priority from higher to lower preference, as available, applying the principle of conservatism in all cases:

1. Tracking records, mobile or desk application, QR code, blockchain technology, GPS use-location coordinates, and any other tracking software that allows for chain of custody record generation from the production facility to the end-use application of biochar.

The project proponent must provide access to all platforms and evidence available to the third party verifier. For non-soil applications such as plastics or asphalt, appropriate monitoring methods (e.g., electronic tracking, satellites, or statistically validated lifetime averages) must be used to ensure the proportion of the material containing biochar is still in use and has not been converted to CO₂ by combustion. From these data, an appropriate decay rate should be formulated (EBC, 2020).

The project proponent shall have an offsite electronic back-up of all logged data.

2. Proof that the biochar has an end-use with a signed attestation from the end-user of the biochar during the monitoring period. This also includes mixing of biochar into agricultural substrates such as fodder, compost, liquid manure, and fertilizer; or non-soils applications (Junginger-Gestrich, 2021).

3. Biochar product confirmation supported by one or more forms of documented evidence such as receipt or invoices, purchase agreement, other.

For 2 and 3, documented evidence must contain biochar batch information, or other identification information, that can be traced to the biochar production and sourcing stage.

To prevent double accounting of carbon benefits, the final location of the site where the carbon sink is created should be registered, where possible. This applies to soil and non-soils applications.

The monitoring plan must contain as a minimum the following information:

- A description of each monitoring task to be undertaken, and the technical requirements therein;
- Definition of the project boundary, especially in the baseline emissions;
- Type of technology for producing biochar;
- Written logs of operation and maintenance of the project system;
- The emissions associated with the project activity;
- The amount of waste biomass pyrolyzed each year and its final use in soil and non-soils applications;
- Roles, responsibilities and capacity of monitoring team and management.

Project proponents must also develop a QA/QC plan to add confidence that all measurements and calculations have been made correctly, and where necessary, correct anomalous values, ensure completeness, perform independent checks on analysis results, and other safeguards as appropriate. QA/QC measures that may be implemented include, but are not limited to:

- Protecting monitoring equipment (sealed meters and data loggers) where applicable;
- Protecting records of monitored data (hard copy and electronic storage);
- Checking data integrity on a regular and periodic basis (manual assessment, comparing redundant metered data, and detection of outstanding data/records);
- Comparing current estimates with previous estimates as a 'reality check';
- Providing sufficient training to personnel to perform activities related to the sourcing, production and application of biochar, and;
- Performing recalculations to ensure no mathematical errors have been made.

All necessary documents must be collected and centrally stored by the project proponent and be available for verification at any time. Documents and records must be stored in a secure and retrievable manner for at least two years after the end of the project crediting period.

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APPENDIX I: ACTIVITY METHOD

As mentioned in Section 7, this methodology uses a standardized approach for the demonstration of additionality, specifically an activity method. Activity methods pre-determine additionality for given classes of project activities using a positive list.

This initial assessment of activity penetration indicates that there is not enough biochar production in any country that would put such penetration above the five percent threshold called for in the *VCS Program Requirements*. It is known that no country has an activity level of penetration higher than five percent at this time due to biochar production constraints.

Per the VCS rules, Verra will reassess whether the activity penetration levels remain within the permitted threshold within three years of the initial approval of the methodology. At that time, Verra will base its assessment on national boundaries, focusing on countries where biochar made from waste biomass has been used. Also, following a conservative scenario, where sub-national regulations or policies may impact the likelihood of the project activity being implemented, Verra may use such boundaries as the basis of the reassessment of the activity level of penetration

A1. Positive List

The project activity production of biochar with waste biomass is a relatively recent field with few fully commercial technologies. Therefore, the methodology uses an activity method for demonstrating additionality, with the processing of waste biomass to biochar as the basis for a positive list. This approach stipulates that the total number of tonnes of waste biomass converted to biochar amounts to less than five percent of the total number of tonnes of waste biomass available worldwide. Five percent is the activity penetration threshold set by the *VCS Methodology Requirements v4.0* and is determined by taking the Observed Activity (OA) divided by the Maximum Adoption Potential (MAP). Where the result of this equation is less than five percent, the project activity may be considered additional.

Activity penetration is calculated as:

$$AP_y = OA_y / MAP_y$$

Where:

<i>AP</i>	Activity penetration of the project activity in year y (percentage)
<i>OA_y</i>	Observed adoption of the project activity in year y
<i>MAP_y</i>	Maximum adoption potential of the project activity in year y

Maximum adoption potential (MAP) of the project activity in year y

The *VCS Methodology Requirements v4.0* defines MAP as “the total adoption of a project activity that could currently be achieved given current resource availability, technological capability, level of service, implementation potential, total demand, market access and other relevant factors within the methodology’s applicable geographically defined market”.

For purposes of this methodology, the maximum adoption potential of this activity is the number of metric tonnes (Mg) of waste biomass that could be converted to biochar worldwide. The carbon sequestration benefits of biochar have been extensively studied over the years, however, the lack of a robust and widely accepted carbon methodology has limited access to carbon markets and finance needed to scale the biochar sector. While there are enormous volumes of waste biomass available globally, commercial implementation constraints (e.g., necessary infrastructure for producing and distributing biochar) and limited market access mean that actual conversion of waste biomass into biochar is a fraction of its potential. This is expected to change as biochar producers and practitioners work to build data sets and complete Research and Development (R&D) trials to prove the material's effectiveness compared to existing competing products (e.g., as a beneficial soil amendment compared to compost and other well-established soil amendments). However, until data on biochar's performance and cost-competitiveness are proved definitively, market access will continue to constrain its use.

Global APy for forestry and agricultural residues

The United Nations Food and Agricultural Organization's (FAO) online FAOSTAT71 database of forestry and agricultural statistics was queried for the total amount of "wood residues". Results indicated that in 2019, there were 336,858,637 cubic meters of wood residues reported by 94 countries worldwide in 2019 (country reporting includes the US, China, UK, Switzerland, as well as many others in the Global South). Wood residues can be in different forms (from sawdust and other wood residues at sawmills to slash piles in the forest to firewood). According to the UK Forest Research agency:

- Industrial roundwood averages 1.43 cubic meters per tonne for softwoods and 1.25 cubic meters for hardwoods.
- Chips and sawdust are 1.48 cubic meters per tonne.
- Fuelwood is 1.38 cubic meters per tonne.

For the sake of conservatism, by taking the least dense metric of 1.25 cubic meters per tonne there are an estimated 421,073,296 metric tonnes of wood residues produced globally on an annual basis⁷².

The same database did not have any similar information on "crop residues", however it did report total tonnes of crops produced globally. The value in 2019 was 11.9 billion metric tonnes of total crops. To be conservative, if only 10% of that value was crop residues, it would be over 1.1 billion tonnes a year (globally) potentially available for conversion to biochar.

Adding 421,073,296 metric tonnes of wood residues to 1.1 billion tonnes of crop residues = 1,521,073,296.

Therefore, for the purposes of this methodology, the maximum adoption potential of this activity is limited to MAPy = 1.521 billion tonnes.

⁷¹ FAOSTAT. 2021. Web query. <http://www.fao.org/faostat/en/#data>

⁷² Available at <https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2016-introduction/sources/timber/conversion-factors/>

Observed adoption of the project activity in year y (O_{Ay})

According to the International Biochar Initiative⁷³, in 2015 a total of 85,000 metric tonnes of biochar were transacted globally. (Figure A1).

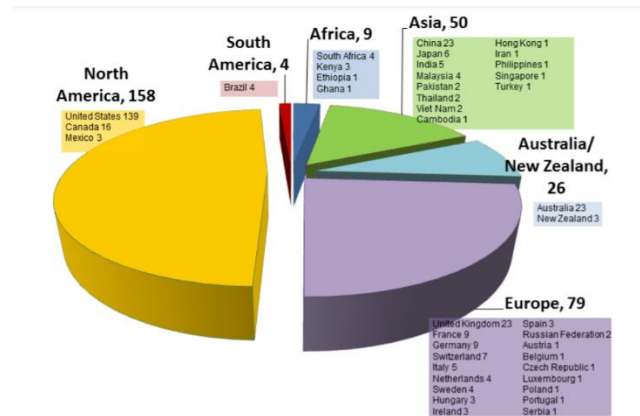


Figure A1. Geographic distribution of biochar producers. Source IBI (2015)

To be conservative, it is assumed that the 2015 IBI report only captured half of the reported transaction volumes or an estimated 170,000 metric tonnes of biochar produced.

Since the last IBI biochar report was published, China has begun to produce a significant amount of material. As of 2019, China was producing 500,000 metric tonnes a year (T.R. Miles pers. comm). According to the National Alliance of Biochar Science and Technology Innovation in China, the country plans to reach 3,000,000 tonnes per year of biochar production in the coming years.

Using the 170,000 metric tonnes (from the 2015 IBI data) and an assumed growth rate of 10% per year for the years 2016 to 2021, that would equal 273,787 metric tonnes for every country besides China. If then it is added 500,000 tonnes to account for China's production the total 2020 global estimate of biochar on an annual basis is 773,787 metric tonnes.

Therefore, the Global AP_y for biochar is:

$$AP_y = O_{Ay} / MAP_y$$

$$AP_y = 773,787 / 1,521,073,296$$

$$AP_y = 0.05\%$$

$$AP_y = < 5\%$$

⁷³ State of the Biochar Industry. 2015. International Biochar Initiative. <https://biochar-international.org/state-of-the-biochar-industry-2015/>

Given the current level of biochar production and waste biomass annually available, it is demonstrated that the activity level of penetration of the project activity covered by this methodology is below the five percent threshold, and the project activity may be deemed additional.

Where the project activity has been commercially available in any area of the applicable geographic area for less than three years (i.e., it uses a new technology or measure), it shall be demonstrated that the project activity faces barriers to its uptake, per the *VCS Standard v4.0* (version 4) requirements.